

Comfort and Functionality of Pregnant Women's Feet

Study of kinetic parameters with silicon insoles

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Resumo

As gestantes, fruto das suas alterações fisiológicas e biomecânicas, constituem uma população de risco relativamente a dores ou lesões do sistema músculo-esquelético, nomeadamente, nos membros inferiores e coluna. Os objectivos deste estudo consistiram em avaliar: (i) a dor e o conforto dos pés durante a marcha: sem o uso de qualquer palmilha nas gestantes e no grupo de controlo; com a aplicação de uma palmilha de retropé e com a aplicação de uma palmilha completa (nas gestantes); (ii) a distribuição das pressões plantares e, (iii) as forças de reacção do solo nas mesmas condições experimentais. Avaliámos ainda a duração das diferentes fases do ciclo de marcha nas gestantes, com e sem palmilhas, e no grupo de controlo, sem o uso de palmilha. Os nossos resultados mostraram que: (i) as gestantes demoram mais tempo a completar a fase de apoio da marcha, (ii) têm um aumento significativo de dores nos pés, face ao grupo de controlo, (iii) as gestantes sentem menos dor e mais conforto quando realizam marcha, com palmilhas, especialmente com a palmilha completa, (iv) a palmilha completa redistribui as forças, diminui os valores de pressão e aumenta a área de contacto do pé com o solo. Os nossos resultados sugerem que, o uso da palmilha completa de silicone, durante a marcha, pode ser eficaz na melhoria da sintomatologia dolorosa e no aumento do conforto da grávida.

Key words: pregnant women, gait, insoles

Abstract

Pregnant women can suffer pains and muscle-skeletal injuries in their feet, lower limbs and vertebral column, due to physiological and biomechanic changes during pregnancy. In this study we assessed the pain and comfort of the feet during gait: without silicone insoles (for pregnant and non-pregnant women); using hindfoot insoles and complete insoles (only for pregnant women). We also measured the plantar pressure distribution, the ground reaction forces and the duration of the gait cycle (for pregnant women with and without insoles; and for non-pregnant women without insoles). Results showed that pregnant women take a significantly ($p=0,001$ right foot and $p=0,03$ left foot) longer time to complete the stance phase, and have significantly ($p=0,03$) more pain and discomfort in the feet, than non-pregnant women. Pregnant women preferred the complete silicone insole because these redistributed ground reaction forces and pressure, and increased the contact area of the feet with the ground. Results suggest that we can relief the pain and discomfort that pregnant women feel in their feet during gait, using a complete silicone insole.

1. Introduction

The main problems during pregnancy are the muscle-skeletal injuries and pains in the feet, lower limbs and vertebral column, due to physiological and biomechanic changes (Foti et al., 2000). Nyska et al. (1997) suggested that physiological changes may be responsible for the faulty foot position of pregnant women that leads to backpain and lower limb pain. The increase of joint laxity and body mass (especially in the anterior/abdominal region of the body) overcharge the joint that provokes the body and seems to be related to the backpain and lower limb pain of pregnant women (Alvarez, 1988; Block, 1985; McNitt-Gray, 1999; Nyska, 1997; Karzel, 1999).

Plantar pressure assessment is an important guide for the foot and ankle function during gait and other functional activities, because the foot and the ankle provide the necessary support and flexibility for the weight bearing and body transfer when a task is performed (Orlin and McPoil, 2000). The identification of the highest pressure areas at an early stage, and the use of appropriate shoes or insoles can be useful in the prevention of ulcers and generalized pain (Schie and Schaw, 1999). The study of the ground reaction forces and the plantar pressure distribution, in the stance phase of gait, provide important knowledge about the form and characteristics of mechanic overcharge of the locomotor system and its behavior during movements (Amadio and Sacco, 1999).

McNitt-Gray (1999) showed, that the vertical component of ground reaction forces became significantly different in dynamic activities during pregnancy. The pregnant women while walking, running and jumping produced forces 2 to 5 times greater a their weight. Horizontal and transversal components of the ground reaction forces can also increase during dynamic activities. Mueller et al. (1991, 1995) suggested that using insoles inside the shoes increased the force, the area, and the capacity of transferring the weight from the calcaneous to the metatarsal region and fingers of the foot. The closer an insole is to the ground, the more therapeutically effective it is, and normally it helps in the transition from the standing phase, and does not significantly affect the alignment of the knee or the hip joints (Edelstein, 1993).

Results from a study by Bird et al. (1999), about gait changes that occur during pregnancy, revealed a significant increase of the stance phase during walking, suggested that the changes in gait function could be a compensatory mechanism to improve locomotor stability and may have important implications for foot function and development of lower-extremity pathology in pregnant woman. It is therefore important to study the adaptation of pregnant women during gait, the interaction between their lower limb and their feet, and also the different pathologies, to better understand these mechanisms and contribute to their well being.

In this study, we assessed the pain and comfort of the feet during gait: without silicone insoles (for pregnant and non-pregnant women) and using hindfoot insoles and complete insoles (only for pregnant women). We also measured the plantar pressure distribution, the ground reaction forces and the duration of the gait cycle (for pregnant women with and without insoles and for non-pregnant women without insoles).

2. Method

Ten healthy women were studied during the last trimester of pregnancy. Their average age was $31 \pm 4,21$ years, they were 161 ± 7 cm high and weighted $68,38 \pm 8,54$ kg. We only selected women in their first pregnancy because the results seem to be different because of the laxity of the pelvic and peripheral joints (Alvarez et al. 1998; Bird et al. 1999). Ten non-pregnant women, the control group, without any prior musculoskeletal problem or deformity, were also studied. They were $29 \pm 3,68$ years old, 163 ± 3 cm high, and weighted $57,04 \pm 10,64$ kg.

All the subjects gave informed consent prior to participation in the study and answered a questionnaire. The questionnaire was used to characterize the subjects and to assess the pain and comfort of their feet during gait. We used a Visual Analogue Scale (VAS) ranging from 0 to 10, where 0 is the total absence of pain and maximum comfort and 10 is the worst imaginable pain and total discomfort. The intensity of pain was classified into the following five categories: 0 – total absence of pain; 1 to 3 – low intensity pain; 4 to 6 – moderate pain; 7 to 9 – intense pain; 10 – the worst imaginable pain (Strong, 2002). The pregnant women assessed the pain they felt and the comfort of their feet with model shoes without insole, with a hindfoot insole and with a complete insole. The model shoes follow the criteria of Vanzant et al. (2001) that proposed a model shoe with a leather and rubber sole to insure comfort, stability and avoid changes to the gait pattern of the subjects. The control group assessed the pain and comfort of their feet, with the same shoes but without insoles.

2.1. Experimental setup

To measure the ground reaction forces we used a *Bertec* force platform with a sampling frequency of 1000 Hz, and a *Bertec AM 6300* amplifier with predefined gain and a 1000Hz low-pass filter. The amplifier was connected to an interface unit *UM 100* and a 16 bit *Biopac Analogic-Digital Convertor (ADC)*. The data collection was synchronized with the acquisition of plantar pressure data.

We studied the distribution of plantar pressure in three settings: without insoles, with a hindfoot insole and with a complete insole. The signals were processed by a PC, using Acknowledge (ACK) and Matlab.

We used a *Pedar* system with a 50 Hz sampling frequency to collect plantar pressure data synchronously with the force platform. The acquisition of data started when the heel contacted the force platform. A signal from the force platform triggered the *Pedar* system. The data acquisition was manually stopped when a gait cycle was completed.

2.2. Experimental protocol

Each subject was measured and weighted without socks, standing on the Bertec force platform, which was setup at the middle of a 5m long and 0,92m wide wooden platform. We then recorded the plantar pressure with the insoles inserted on the model shoes between the plantar surface and the shoes so that there wouldn't be any changes in gait. We used hindfoot and complete silicone insoles, because they have been shown to be the most effective in the redistribution of forces in the foot plant (Curryer and Lemaire, 2000). The silicon insoles contacted the plantar surface and the *Pedar* insoles were inserted between the silicone insoles and the shoes.

The subjects walked along the platform a few times so that they were familiarized with the instrumentation and could practice their normal gait cycle. The velocity of gait was not controlled because we didn't want to constraint the velocity, the length of footstep or its frequency. We registered three walking trials for each foot.

We assessed the ground reaction force components and the plantar pressure using three different protocols: 1 – assessment of the stance phase of gait without insoles (pregnant and non-pregnant women); 2 – assessment of the stance phase of gait with a hindfoot insole (pregnant women); 3 – assessment of the stance phase of gait with a complete insole (pregnant women).

2.3. Analysis

The ground reaction force components data was analyzed and different transition phases were annotated. We measured the following durations of the different phases, related to the vertical component (F_z) as shown in Figure 1: T1 – from the beginning of the standing phase to the first maximum (F1); T2 – from the first maximum to the minimum (F2); T3 – from the minimum to the second maximum (F3); T4 – from the second maximum (F3) to the end of the standing phase.

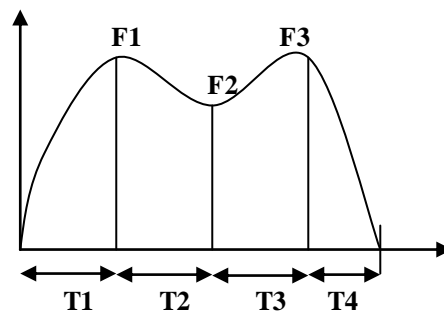


Figure 1: Different phases of the vertical component of the GRF (F_z).

We also measured the duration of the following phases of the anterior-posterior or horizontal component (F_y), as shown in Figure 2: T5 - from the beginning of the standing phase to the minimum (F_4); T6 – from the minimum to the zero crossing (F_5); T7 – from the zero crossing to the maximum (F_6); T8 – from the maximum (F_6) to the end of the standing phase.

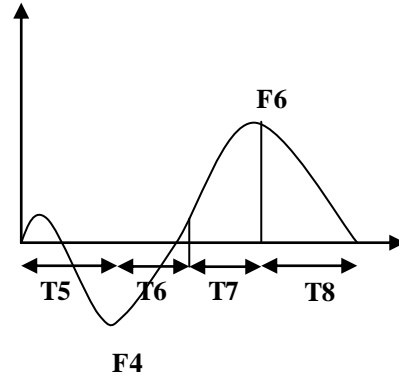


Figure 2: Different phases of the anterior-posterior component of the GRF (F_y).

We calculated the absolute maximum value, the root mean square (RMS) value

$$(1) \text{ RMS} = \frac{1}{SP} \times \int_0^{SP} Fx^2$$

and a relative value

$$(2) \text{ PV} = \frac{\text{RMS} \times 100}{\text{Body Mass}}$$

of the medium-lateral or transversal component (F_x). The RMS value of the transversal component is related to the efforts or corrections that the subjects exert to maintain the equilibrium. The relative value of the RMS of F_x (PV) is a standard way of normalizing the results to the weight of the subjects (Medved, 2001). In fact, all force values were normalized to the body weight ($\text{Force}_{\text{normalized}} = \text{Force}/\text{Body weight}$) and the time values were normalized to the stance time ($\text{Time}_{\text{normalized}} = \text{Time of one phase}/\text{Total time of the stance phase}$) of each subject.

The greatest pressure areas during the stance phase were studied with a *Pedar* system, which allowed us to relate the pressure areas with the different peaks and troughs (and different phases) of the ground reaction forces, and also to characterize the contact areas in the foot during the step. The distribution of the plantar pressures in gait was analysed using a plantar surface map where the foot was divided into four areas: hindfoot, midfoot – medial, midfoot – lateral and forefoot. Manfio et al. (1995) found that it is hard to determinate the exact location of the metatarsal heads and the support of the fingers, so they proposed a broad division of the foot to avoid mistakes in the selection of different areas in each subject. After the selection of the areas, we calculated the values of the pressure and normalized them using the technique proposed by Carmines et al. (1999), considering only the cells that were active. Manfio et al. (1995) described that, when a subject used an insole, the contact area of the foot was inferior to the total area of the insole and some cells were not pressed.

Data were imported into a standard spread sheet (Ms Excel) and analysed with SPSS. We calculated the average and the standard deviation of the variables related to each subject in the different experimental protocols (without insoles, with a hindfoot insole and with a complete insole). We ran normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) and tested the homogeneity of variance, before we performed a one-way-analysis of variance (ANOVA), and multiple comparison pos hoc test (Bonferroni) and independent t-test. The significance level we used was $p \leq 0,05$.

3. Results and discussion

Results showed that pregnant women feel a moderate intensity of pain and that they lack comfort in the feet (an average score of 4,79 and a standard deviation of 1,78), and also that the control group had negligible pain and discomfort ($2,93 \pm 1,74$). Results were significantly different between the two groups ($p=0,03$) and revealed that pregnant women had a significant increase of pain in their feet (Bird et al. 1999). It has been show (Block, 1985; Alvarez, 1988; Nyska et al., 1997; McNitt-Gray, 1999) that ligament laxity due to changes of the mechanical charge, can produce serious mechanical consequences for the pregnant women and that it is related to backpain and lower limb pain. Relaxin hormone affects the ligaments of the foot as well, resulting on changes in foot mechanics (Nyska et al. 1997). There is also a significant increase in the foot volume: 5,72 millimetres during the 13th and the 38th week of pregnancy due to oedema and reducing the free space in the tight anatomic areas, such as the feet (Alvarez et al., 1988).

Pregnant women, during gait without insoles, evaluated their pain and comfort at level 4, 79 (moderate pain and need of comfort) however when we inserted the hindfoot insole, the values decreased to $2,65 \pm 2,21$ (negligible pain and lack of comfort). With the complete insole the results were close to zero ($0,83 \pm 0,97$), as shown in Figure 3. The study of Gross et al. (1991) also showed that athletes using insoles during gait, described a total relief of symptoms.

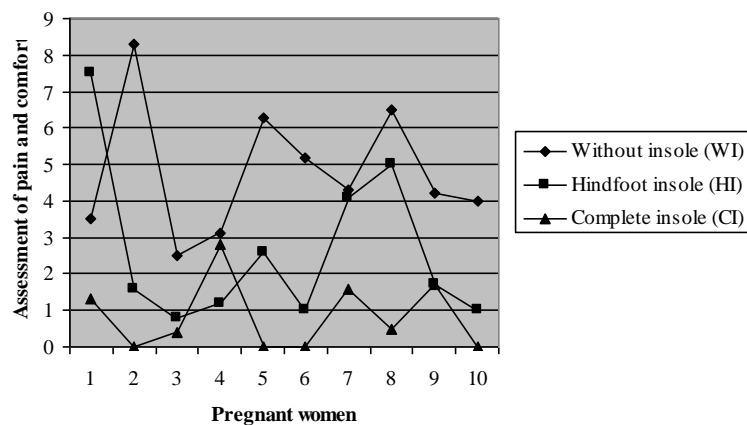


Figure 3: Assessment of pain and comfort in Pregnant Women, Without Insoles (WI), with Hindfoot Insole (HI) and with a Complete Insole (CI).

3.1. Time, force and pressure: pregnant women vs control group

Temporal variables related to the vertical component of ground reaction forces, shown in Table 1, revealed that pregnant women need a longer time to complete the initial contact and loading response (T1) than the control group. The difference was significant ($p=0,039$) for the right lower limb and for the left lower limb ($p=0,021$). The pregnant women take less time than the control group to reach the mid-stance phase (T2). The difference was statistical significant only for the right foot ($p=0,012$). The pregnant women transfer their weight to the supporting lower limb more slowly, to control the movement of the heel strike and of the loading response, and to achieve faster the mid-stance phase. During this phase (passive phase of gait), pregnant women absorb larger amounts of energy. The dorsiflexion of the toes, that occurs in the second half of the stance phase as the heel leaves the ground, increases tension in plantar aponeurosis (Nyska et al., 1997). This increase of tension together with the increase of body mass in the anterior region of the trunk, provoke the release of accumulate energy, so pregnant women take less time to complete this second part of the stance phase.

Duration (s)	Right Foot			Left Foot		
	Pregnant women	Control Group	p	Pregnant women	Control Group	p
T1	0,33±0,04	0,30±0,03	0,039*	0,31±0,03	0,27±0,03	0,021*
T2	0,16±0,03	0,21±0,04	0,012*	0,19±0,05	0,22±0,06	0,329
T3	0,28±0,03	0,26±0,02	0,169	0,25±0,05	0,27±0,05	0,429
T4	0,23±0,03	0,24±0,04	0,853	0,24±0,02	0,23±0,03	0,744

Table 1: Results of an *Independent t-test*. Average and standard deviation of durations of the different phases of the vertical component (Fz) of the GRF in pregnant women and the control group (* $p \leq 0,05$).

The duration results of the horizontal component of the GRF, shown in Figure 4, did not reveal significant differences between pregnant women and control group. We believe that this is related to the posture adjustment to maintain the equilibrium in pregnant women.

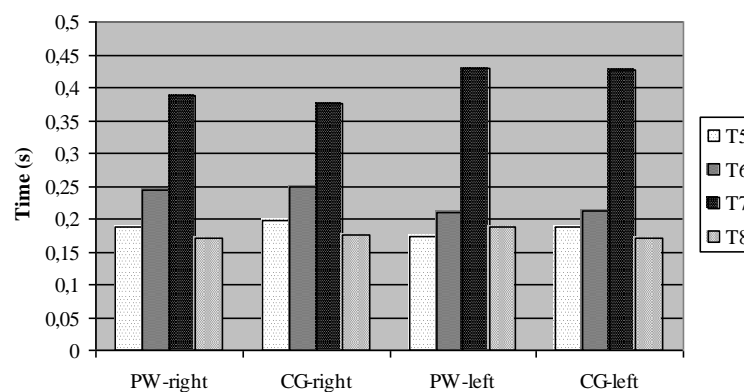


Figure 4: Average duration of different phases of the horizontal component of GRF. PW stands for Pregnant Women and CG stands for control group.

Pregnant women take a significantly longer time to complete the stance phase of gait than the control group ($p = 0,001$ - right foot and $p = 0,03$ - left foot). Our results, shown in Figure 5, are similar to those of Campos (1997), Nyska et al. (1997) and Bird (1999), who suggested that this alteration in the gait, is necessary compensatory mechanism to improve stability of the locomotor system with significant implications on the foot function and on the development of pathologies in the lower limb of pregnant women.

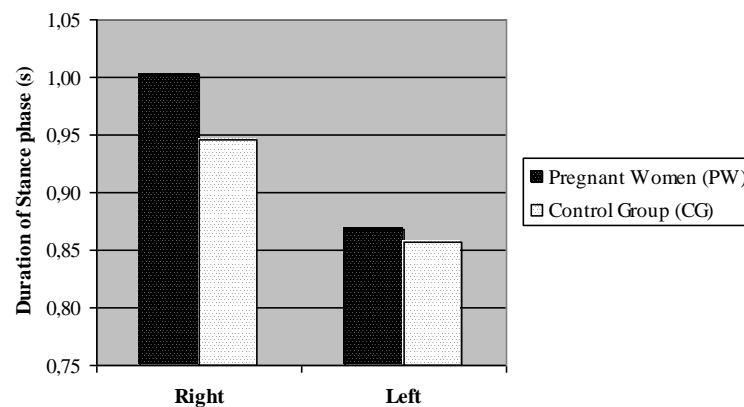


Figure 5: Average stance phase duration of pregnant women and the control group.

The forces (F2) exerted by pregnant women were higher than those exerted by the control group during mid-stance. During the terminal contact and pre-swing (F3) the forces developed by pregnant women were lower than the control group, as shown in Table 2. Pregnant women took a longer time to complete T1, but had more body mass. Therefore, they developed a higher shock absorption, which resulted in the same set of force values as the control group. The higher values of F2 seem to be related to the vertical posture of pregnant women which is determined by their centre of gravity. The body mass and the contralateral lower limb in a swing phase lead to lower values of F3.

Force	Right foot			p	Left foot		
	Pregnant women	Control group			Pregnant women	Control group	p
F1	1,04±0,02	1,06±0,04		0,183	1,04±0,02	1,06±0,05	0,437
F2	0,93±0,03	0,87±0,06		0,017*	0,93±0,04	0,89±0,07	0,115
F3	1,08±0,02	1,12±0,05		0,074	1,09±0,03	1,13±0,05	0,039*

Table 2: Results of an *Independent t-test*. Average and standard deviation of forces of the different phases of the vertical component (Fz) of the GRF in pregnant women and the control group (* $p \leq 0,05$).

Negative values of the horizontal component of the GRF, shown in Table 3, represent the slowing down phase of gait. We've shown that pregnant women take a longer time to complete the heel strike and the loading response phases which allow them to brake more slowly than the control group and to better control the force values. The positive values of the horizontal component correspond to the acceleration phase of gait. During this phase, pregnant women need to project their centre of gravity forward to initiate the swing phase and transfer their weight to the other lower limb. The increase in body mass in the anterior region of the trunk contributes to the impulsion force during this phase.

Force	Right foot			p	Left foot		
	Pregnant women	Control group			Pregnant women	Control group	p
F4	0,07±0,03	0,08±0,03		0,720	0,06±0,02	0,08±0,03	0,341
F6	0,16±0,02	0,19±0,03		0,025*	0,18±0,02	0,20±0,03	0,143

Table 3: *Independent t-test* results. Average and standard deviation of the horizontal component of the GRF of pregnant and non-pregnant women (* $p \leq 0,05$).

Pregnant women have larger contact areas in all areas of the foot, than the control group. Nyska et al. (1997) showed similar results, pointing out that contact areas of the foot in pregnant women were 8% higher than non-pregnant women. The mean and maximum pressures, in the different areas of the feet of pregnant women, and the whole duration of the stance phase, were also lower than the control group (Nyska et al., 1997).

3.2. Time, force and pressure: pregnant women and the use of insoles

Results showed that the use of insoles did not change the duration of the phases of the vertical component of the GRF. Analysis of the horizontal component of GRF, shown in Table 4, suggest that the insoles do not change the first part of the slowing down phase, but the second part is slower so pregnant women have a longer time to adapt to the loading response. We also found a decrease of the acceleration phase. Therefore, we can conclude that pregnant women with insoles brake for a longer time but impulse faster.

	Right foot				Left foot			
Durations (s)	PW - WI	PW - HI	PW - CI	p	PW - WI	PW - HI	PW - CI	p
T5	0,18±0,04	0,19±0,04	0,18±0,05	0,944	0,17±0,03	0,18±0,03	0,18±0,03	0,802
T6	0,24±0,06	0,29±0,11	0,29±0,07	0,366	0,21±0,06	0,22±0,07	0,23±0,06	0,771
T7	0,38±0,07	0,35±0,11	0,34±0,08	0,609	0,42±0,06	0,40±0,09	0,39±0,05	0,586
T8	0,17±0,02	0,16±0,02	0,17±0,02	0,646	0,18±0,02	0,19±0,03	0,18±0,02	0,790

Table 4: One-way-anova results. Average and standard deviation of the duration of the horizontal component of the GRF of Pregnant Women (PW), Without Insoles (WI), with a Hindfoot Insole (HI) and with a Complete Insole (CI) (* $p \leq 0,05$).

The stance phase takes longer when the complete insoles are worn by pregnant women as shown in Figure 6. Winter (1991) suggested that it is possible re-establish the equilibrium by increasing the total time of the stance phase and by reducing the angle of the initial contact.

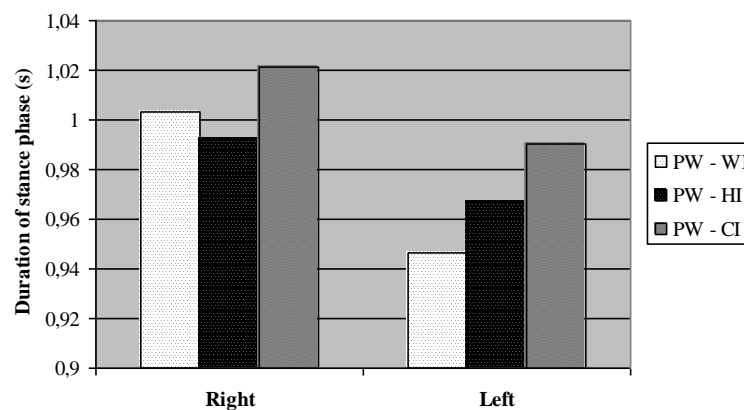


Figure 6: Duration of the stance phase of the gait of Pregnant Women (PW) Without Insole (WI), with Hindfoot Insole (HI) and with a Complete Insole (CI).

The maximum values of the vertical and horizontal components of the GRF decreased with the insoles, especially with the complete insole.

The insoles increased the contact area, so they decreased the pressure values and the pain and discomfort of pregnant women. The hindfoot insole increased only the forefoot area so the pressure was concentrated in this area. The complete insoles increase all contact areas, including the medial and lateral midfoot, redistributing the pressure values for all the areas of the feet. Our results support those of Know and Mueller (2001), who suggested that we could reduce the plantar pressure by distributing the weight through the whole plantar surface during gait, therefore reducing the plantar pressure in critical points (hindfoot and forefoot) and slightly increasing the pressure in the midfoot. Wilson (1992) also showed that the cause of discomfort could be the higher levels of pressure and suggested a uniform pressure distribution.

Our analysis of maximum pressures revealed that the hindfoot insole did not decrease the pressure when compared to the situation without insole. The complete insole decreased the maximum pressure in all the contact areas of the feet with the ground, except the midfoot values, that showed the same values or a slight increase. Know and Mueller (2001) showed that the highest pressure values were exerted in forefoot in pre-swing phase (F3), because in this phase the heel leaves the ground and the body weight is transferred to the forefoot and fingers. Therefore, this is an important variable when we study the plantar pressure distribution or the efficiency of some insole material during gait. Amadio and Sacco (1999) also showed a predominance of pressure peaks in the anterior region of the foot and consequently more pain in this location. Therefore, it is important to decrease the pressure values in the forefoot of pregnant women.

4. Conclusions

Our results show that pregnant women, during gait without insoles, have more pain and discomfort than control group women. However, their pain and discomfort are reduced when they walk with insoles especially with the complete one.

Pregnant women have higher minimum values of the vertical component of the GRF, than the control group. The other values of this component did not present a significant difference. The maximum values of the horizontal component of pregnant women were lower than the control group.

When pregnant women walked, they contacted the ground with a larger area of the feet, which decreased the mean and maximum values of pressure. This compensatory mechanism decreased the maximum pressure of the midfoot (lateral and medial) and forefoot during the mid-stance.

We also found that pregnant women took longer to complete the stance phase of gait than non-pregnant women, and produced fewer medio-laterals movements to maintain the equilibrium.

With the complete insole the pressure values were efficiently redistributed for the entire plantar surface. The hindfoot insole did not change significantly the mean pressure values of the hindfoot, but increased them in the forefoot. The maximum pressure only decreased with the complete insole.

Therefore, the hindfoot insole can be useful to decrease the pain and increase the comfort of the feet in pregnant women, but the complete insole is more efficient, because the pregnant gait is less painful and more comfortable.

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